XTE J1550-564: INTEGRAL Observations of a Failed Outburst

S. J. Sturner and C. R. Shrader

Laboratory for High Energy Astrophysics, Code 661, NASA,Goddard Space Flight Center, Greenbelt, MD 20771

and

Universities Space Research Association, 10211 Wincopin Circle, Suite 620, Columbia, MD 21044

ABSTRACT

The well known black-hole X-ray binary transient XTE J1550-564 underwent an outburst during the spring of 2003 which was substantially underluminous in comparison to previous periods of peak activity in that source. In addition, our analysis shows that it apparently remained in the hard spectral state over the duration of that outburst. This is again in sharp contrast to major outbursts of that source in 1998/1999 during which it exhibited an irregular light curve, multiple state changes and collimated outflows. This leads us to classify it as a "failed outburst." We present the results of our study of the spring 2003 event including light curves based on observations from both *INTEGRAL* and *RXTE*. In addition, we studied the evolution of the high-energy 3-300 keV continuum spectrum using data obtained with three main instruments on *INTEGRAL*. These spectra are consistent with typical low-hard-state thermal Comptonization emission. We also consider the 2003 event in the context of a multi-source, multi-event period-peak luminosity diagram in which it is a clear outlyer. We then consider the possibility that the 2003 event was due to a discrete accretion event rather than a limit-cycle instablility. In that context, apply model fitting to derive the timescale for viscous propagation in the disk, and infer some physical characteristics.

Subject headings: accretion—stars: radiation mechanisms: nonthermal – stars: black holes – stars: individual (XTE J1550-564) – gamma rays: observations

1. INTRODUCTION

Black hole X-ray transients, also referred to as X-ray novae or soft X-ray transients (Chen, Shrader & Livio 1997; McClintock, J. & Remillard 2004), are a class of low-mass X-ray binaries (LMXBs) in which long periods of quiescence, often decades, are interupted by dramatic X-ray and optical/UV outbursts, frequently accompanied by radio emission which is sometimes associated with collimated outflows. The X-ray binary XTE J1550-564 is an example of this class of objects. It was discovered in 1998 (Smith et al. 1998), at which time it underwent a period of major outburst, surging to perhaps its Eddington luminosity assuming the distance and mass estimates of (Orosz et al. 2002). This initial event, which exhibited a variety of complex behavior including an irregular light curve, spectral state transitions, and quasi-periodic oscillations, lasted for $\sim$200 days (e.g. Sobczak et al 2000; Homan et al 2001; Remillard et al. 2002). Radio monitoring during the X-Ray outburst recorded a radio flare, and subsequent VLBI radio observations soon thereafter showed evidence for a superluminal jet ejection event (Hannikainen et al. 2001). Subsequently, the jet has been detected in X-rays using *Chandra* and has been shown to be decelerating (Corbel et al. 2002; Tomsick et al. 2003; Kaaret et al 2003). Given these discoveries, XTE J1550-564 has been classification as a Galactic microquasar.

Another major, although less luminous than the first, outburst occured about 1.5 years later. Since mid-2000, the source has remained active, exhibiting spoaradic, low-amplitude flaring episodes. It has been suggested that these occur at nominal 1-year intervals, but this pattern is not well quantified. A long-term light curve illustrating these basic features is presented in Figure 1.

Early in 2003, during a Galactic plane monitoring scan, the INTErnational Gamma-Ray Astrophysical Laboratory (*INTEGRAL*) (see Winkler et al. 2003, for a description of INTEGRAL and the Galactic plane monitoring program), detected the onset of outburst activity in XTE J1550-564 in the hard (>20 keV) X-ray band (Dubath et al. 2003; Arefiev et al. 2004). Subsequently, a series of ToO observations were carried out. The source was also observed with Rossi X-Ray Timing Explorer (*RXTE*), both with pointed observations as well as essentially continuous monitoring with the All-Sky Monitor (ASM). In this paper we present our analysis and interpretaion of these data.

We briefly discuss the instruments onboard *INTEGRAL* in §2. Our analysis of the *INTEGRAL* and *RXTE* observations is presented in §3 . This includes light curve analysis as well as our spectral model fitting and interpretation. In §4 we discuss the low-amplitude hard-spectral state outburst of XTE J1550-564 in the context of models for X-ray nova outbursts, and spectral state transitions. Some conclusions are drawn in §5.

2. INSTRUMENTATION - INTEGRAL

INTEGRAL was launched into a 3-day elliptical orbit on October 17, 2002. It carries four instruments, three of which have been used for our analyses: the imager IBIS (Ubertini et al. 2003), the spectrometer SPI (Vedrenne et al. 2003), and the Joint European X-Ray Monitor, JEM-X (Lund et al. 2003). For a complete description of the *INTEGRAL* spacecraft and mission refer to Winkler et al. (2003).

IBIS is a coded mask instrument which has a wide field of view (FOV) of $29^\circ \times 29^\circ$ ($9^\circ \times 9^\circ$ fully coded) with a point spread function (PSF) of $12'$ (FWHM) and is sensitive over the energy range 15 keV to 10 MeV. There are two detector layers: ISGRI, an upper CdTe layer with peak sensitivity between 15 and 200 keV, and PICsIT, a bottom CsI layer, with a peak sensitivity above 200 keV. In this paper we have used only ISGRI data.

The Spectrometer on Integral, SPI, covers the 20 keV - 8 MeV energy range with an energy dependent resolution of 2-8 keV (FWHM). It consists of an array of 19 hexagonal high-purity Germanium detectors. A hexagonal coded aperture mask located 1.7 m above the detection plane images large regions of the sky (fully coded field of view 16°) with an angular resolution of $\sim 2.5^\circ$.

The Joint European X-ray Monitor telescope, JEM-X, detection plane consists of two identical high-pressure imaging microstrip gas chambers. Currently, only one telescope/detector is in operation at a time. Each detector views the sky through a coded aperture mask. During the observations analyzed in this work, only the JEM-X 2 telescope was operational.

3. DATA ANALYSIS AND RESULTS

We have analyzed the SPI, IBIS/ISGRI and JEM-X data collected between January 29, 2003 and April 12, 2003 in a series of dither pointings or "Science Windows" (SCWs) lasting about 30-40 minutes each. These include Core Program data from the Galactic Plane Scans (GPS) and the Galactic Center Deep Exposure (GCDE) as well as data from a series of Target of Opportunity (ToO) observations activated as part of the General Program (see Winkler et al. 2003). Data reduction was performed using the standard OSA 4.1 analysis software package available from the *INTEGRAL* Science Data Centre. The data were downloaded from the HEASARC mirror to the *INTEGRAL* Public Data Archive. Only SCWs with pointing direction within a specified angular radius were accepted. This radius varied for each instrument. We chose to use a 12° radius for SPI, a 10° radius for IBIS/ISGRI, and a 2° radius for JEM-X. These large angular cuts were only relevant for SPI and ISGRI data prior to the outburst. During the ToO pointed observations the angular distance off-axis was never greater than 6°. In addition to the *INTEGRAL* data, we obtained the relevant *RXTE*/ASM data from the ASM light curve archive http://xte.mit.edu/ASM_lc.html.

3.1. Imaging and Light Curves

The long term X-ray light curve for XTE J1550-564 is shown in Figure 1. The *RXTE*/ASM daily summations depicted there show the highly variable nature of this source. The major outbursts in 1998-1999 (Smith et al. 1998) and 2000 (Rodriguez, Corbel, & Tomsick 2003) are very prominent. The current outburst, indicated by the vertical dashed line, is quite modest in comparison. The January - April 2003 light curves for XTE J1550-564 as seen by IBIS/ISGRI and *RXTE*/ASM are depicted in Figure 2. In panels 2b - 2d we show the ISGRI light curves for the 15-40 keV, 40-100 keV, and 100-200 keV bands, respectively. Each data point represents the average count rate for an individual SCW, $\sim$ 2000 seconds. In panel 2a we show the *RXTE*/ASM 1.5 - 12 keV light curve. Each data point there is for a daily average.

The *RXTE*/ASM light curve shows that this outburst began on or about March 21, 2003 (MJD 52719) and lasted for roughly 45 days. There is a broad peak lasting $\sim$ 20 days with a peak count rate of 4.86 cts s^{-1} or $\sim$64 mCrab. The IBIS/ISGRI light curve is less continuously sampled than the *RXTE*/ASM one. The outburst was first detected with ISGRI during *INTEGRAL* revolution 54 on March 24, 2003 during a GPS observation. An *INTEGRAL* ToO was triggered and pointed observations commenced during revolution 55 on March 27, 2003 and continued during revolutions 57 and 58, and ended during revolution 60 on April 12, 2003. Hence there is no ISGRI data during the initial rise phase nor any during the decay. The shapes of the light curves in the three ISGRI energy bands are very similar but there is a suggestion that the rise in the 100-200 keV band was slightly faster than the lower energy bands. The peak count rates in the 15-40 keV, 40-100 keV, and 100-200 keV energy bands are 37.6 cts s^{-1}, 35.2 cts s^{-1}, and 9.11 cts s^{-1}, respectively. In Figure 3 we show the IBIS/ISGRI mosaic images for revolutions 54, 55, 57, and 60 which show the distinct turn-on of XTE J1550-564 during this time period.

The major outbursts of 1998-1999 and 2000 showed transitions from a power law dominated low hard state to a high soft state that had a strong thermal component. We looked for similar transitions in the 2003 outburst by examining hardness ratios. Using *RXTE*/ASM data, we calculated hardness ratios for the large September 1998 - January 1999 outburst as well as the March-April 2003 outburst. In this paper we define the hardness ratio when comparing two energy bands as (H-S)/(H+S) where H is the count rate in the higher energy band and S is the rate in the lower energy band. In Figure 4 we compare the hardness ratios for the two different outbursts using the 1.5-3 keV (A) and 5-12 keV (C) energy bands of the *RXTE*/ASM. For the March-April 2003 outburst the hardness ratio is approximately constant with a value of ~0.3. In contrast, the hardness ratio during the large September 1998-January 1999 burst varied significantly over its duration. During the initial flare the hardness ratio was similar to the 2003 burst with values near 0.3. The hardness ratio quickly decreased to an almost constant value near -0.1. During the second peak in January 1999, the hardness ratio was even smaller with values near -0.3. This in agreement with Sobczak et al (2000) who noted that the first peak of the outburst was generally dominated by power-law emission while the second peak was dominated by softer thermal disk emission. Thus we find that not only is the March 2003 event of signifcantly lower luminosity, it is also appears to never leave the conical low hard state. We will examine this further in the next section when we discuss our spectroscopy results.

3.2. Spectral Analysis

We performed spectral analysis of the JEM-X, IBIS/ISGRI, and SPI data during the March-April 2003 outburst using OSA 4.1 software. For JEM-X and ISGRI, individual spectra are produced for each SCW. For strong sources such as XTE J1550-564 during this outburst, these individual SCW spectra can be easily combined to improve there statistical significance and for direct comparison with SPI spectra. We used the OSA utility program *spe_pick* to combine the JEM-X spectra by revolution. The IBIS/ISGRI spectra were similarly combined using the FTOOL *mathpha*. SPI is a coded mask telescope like IBIS and JEM-X. But unlike these other instruments, it is not possible to extract spectra for individual SPI pointings due to its relatively small number detectors and mask elements. Thus for SPI one can only extract spectra for a series of pointings. In this case we chose to extract one spectrum for each of revolutions 55, 57, and 60 using all the relevant SCWs in a given revolution. We then performed a simultaneous fit of the SPI, IBIS/ISGRI, and JEM-X data, for each of the 3 revolutions, in XSPEC v.11.3.1. We explored fits using the COMPST (Sunyaev & Titarchuk 1980) and COMPTT (Titarchuk 1994) thermal Comptonization models. During the fitting procedure the model normalization was allowed to vary from instrument to instrument . A systematic 5% error was added to the IBIS/ISGRI data in order to achieve reasonable χ^2 values (see e.g. Goldwurm et al. 2003).

We found that the COMPTT model provided a statistically significant better fit to the data for each revolution. Using an FTEST, the probability that the reduction in χ^2 that occurred when changing from the COMPST to the COMPTT model resulted from mere chance was never greater than $\sim 5 \times 10^{-11}$. The complete results of our fitting procedures are given in Table 1. In Table 2 we give the integrated COMPTT model fluxes in the JEM-X, IBIS/ISGRI, and SPI energy bands. Note that there is a significant yet consistent normalization difference between IBIS/ISGRI and SPI. These cross calibration issues have been previously noted, see e.g. Courvoisier et al. (2003). In Figures 5 & 6 we show the spectral fits to the data from revolutions 55, 57, and 60 using the COMPTT model. In Figure 7 we show the 90% confidence contours for the kT and τ_p COMPTT model parameters for each revolution. There is a strong suggestion of spectral evolution to lower kT and higher τ_p with time. No Fe line structure is evident at the resolution and sensitiviy of JEM-X.

Thus the spectra from each of the three revolutions are well fit by the COMPTT thermal Comptonization model which produces essentially a cutoff power-law spectrum. We again find no indication of a transition from the low hard state to a disk dominated high soft or intermediate state as was seen in the major outbursts in 1998-1999 (Sobczak et al 2000) and 2000 (Rodriguez, Corbel, & Tomsick 2003).

Finally, in addition to the static thermal Comptonization models, we considered Comptonization by an expanding plasma ambient to the central compact object. It was recently shown that the presence of such an outflow is likely to produce a net down-scattering of the emerging photon field – thus, a hardening of the spectrum in the $\sim 20 - 100$ keV region (Titarchuk & Shrader 2004). Since plasma ejection as evidenced from radio emission is believed to accompany the high-soft to low-hard state transition, one might conjecture that the hard-state turn on in these types of flares could also involve outflowing plamsa. We found that the model described by Titarchuk & Shrader (2004) led in some cases to a slightly improved fit; for revolution 57 for example, we obtained 271/205 compared to 279/205). We thus suggest that our results are consistent with scenarios involving plamsa ejection. However since this is a model dependent conclusion, in the absense of supporting observational data such as the onset of radio emission we are reluctant to draw strong conclusions.

4. DISCUSSION

Rodriguez, Corbel, & Tomsick (2003) showed that during the April 2000 outburst of XTE J1550-564 there was spectral evolution from the low hard state to a softer intermediate state as the luminosity increases and then back to the low hard state as the source luminosity declines. The transitions from one state to another were rather abrupt and were described as a phase transition with hysteresis, i.e. the hard-to-soft transition occurs at a higher flux than the soft-to-hard transition. This hysteresis effect has been previously noted, e.g. Miyamoto et al. (1995). The initial transition from the low hard state to the intermediate state was shown to occur when the integrated 2 - 200 keV flux reached $\sim 2.3 \times 10^{-8}$ ergs cm^{-2} s^{-1}.

The transition from the intermediate state back to the low hard state for the 2000 outburst occurred a flux of $\sim 1.3 \times 10^{-8}$ ergs cm^{-2} s^{-1}. Comparing the 2000 and 2003 outbursts, the 2-200 keV integrated flux for the March 2003 outburst was only $F_{20-200} \lesssim 10^{-8}$ ergs cm^{-2} s^{-1}, thus never reaching the flux where Rodriguez, Corbel, & Tomsick (2003) saw a transition to the intermediate state.

Assuming a distance to XTE J1550-564 of 5.3 kpc and a black hole mass of 9.4 $M_\odot$ (Orosz et al. 2002), the corresponding 2 - 200 keV luminosities at which the hard-to-soft (H-S) and soft-to-hard (S-H) transitions occurred during the the 2000 outburst are $L_{\rm H-S,2000} = 7.7\times10^{37}$ ergs s^{-1} = $0.063L_{\rm EDD}$ and $L_{\rm S-H,2000} = 4.4\times10^{37}$ ergs s^{-1} = $0.036L_{\rm EDD}$. During the 1998-1999 outburst, the transition from the high soft state to the low hard state occurred at a luminosity $L_{\rm S-H,1998} = 0.034L_{\rm EDD}$ (Maccarone 2003; Sobczak et al 2000). Thus the luminosity at which the soft-to-hard transition occurs is consistent between the two major outbursts. They are also consistent with theoretical predictions of state transitions at luminosities near $0.02 - 0.05L_{\rm EDD}$ if one accounts for the hysteresis effect (Meyer-Hofmeister 2004; Meyer et al 2000). For the 2003 outburst, we find that the 3 - 300 keV flux during revolution 57 was 9.9×10^{-9} ergs cm^{-2} s^{-1} if we use the ISGRI normalization for the COMPTT model. This corresponds to a 3 - 300 keV luminosity of 3.3×10^{37} ergs s^{-1} = $0.027L_{\rm EDD}$ which is toward the lower bound of the theoretical range of luminosities where a transition could occur. Thus the 2003 outburst of XTE J1550-564 could be classified as a failed major burst in which the luminosity never reached the point of spectral transition.

The fact that XTE J1550-564 remained in it low-hard spectral state during the 2003 outburst (and possibly in other minor outbursts over the last several years) poses some interesting challenges to the disk-thermal-instability model for outbursts. This is the case both because of the relatively long binary period, 1.54 days (Orosz et al. 2002), and the implied large separation and accretion disk, as well as because of the frequency of the outbursts.

In one commonly accepted view of black hole X-ray transients, the low-mass companion star undergoes roche-lobe overflow, but at a sufficiently low rate that the gas is accumulated in the (cool) disk until a critical level is reached, at which point the outburst occurs (e.g. Lasota 2001; Meyer-Hofmeister 2004). Just what this critical level of accumulated mass is unclear, but it is certain to depend on the size of the disk, and thus the binary separation. This behavior is analogous to the outburst cycles seen in dwarf novae, however the recurrence timescales for X-ray transients are longer and less regular. In between outbursts, the accretion rate is low, and it is conjectured that an advection-dominated region fills the inner disk. The spectrum is hard (photon indices $\Gamma \sim 1.5 - 1.9$) and consistent with models of thermal Comptonization. Most often, in outburst the spectrum changes to a ~ 1 keV thermal spectrum, often interpreted as the radiation from a geometrically thin, optically thick disk, superposed on a softer power law (photon indices $\Gamma \sim 2 - 3$) extending to 10's or 100's of keV. Such spectral state transitions are also well known in persistent X-ray binary sources.

It has been suggested (e.g. Nowak 1995; Meyer-Hofmeister 2004) that whether or not a spectral-state transition occurs depends on the value of $\dot{m}$. In the ADAF model, the mass inflow rate must be sufficient to overcome the transition to the two-temperature (electron-ion) plasma, so that it can extend close to the innermost stable orbit (Meyer et al 2000). The details of this process may be crucial to a complete understanding of spectral-state transitions. It may be the case that for low $\dot{m}$ regimes, sources remain in the low hard state. Meyer-Hofmeister (2004) have suggested that short-period systems (short in this context being $P \sim$5 hours or less), by virtue of their smaller binary separations and correspondingly smaller accretion disks, would naturally have outbursts of lower luminosity. Additionally, the efficiency with which the ADAF corona is produced may depend on the inner disk radius, and may be bounded by some maximum value.

Historically, it is notable that a few of the transient LMXBs remain in the low hard state during outburst, e.g. GRO J0422+32, GRO J1719-24 and XTE J1118+480 (e.g. Brocksopp 2001). But in two of these cases at least, the orbital periods are small, 4.1 hours for XTE J1118+480 and 5.1 hours for GRO J0422+32 (McClintock, J. & Remillard 2004). Thus implying small accretion disks and accumulated reservoirs of matter. Given XTE J1550-564's relatively long orbital period, the disk is large among LMXBs; $R_d \sim 3.5 - 4.0 \times 10^{11}$ cm. Thus the mass accumulated in the accretion disk between outbursts should be relatively large. How then are these small outbursts produced? One possible explanation is that discrete accretion events can somehow occur in which only part of the inner disk is disrupted.

In view of the substantial differences between the major outbursts and the subsequent minor flaring events – in terms of the peak luminosities, the light curve shape and duration, as well as the hardness ratio and the recurrence frequency of similar events – one might speculate that some mechanism other than the thermal limit cycle could be occurring.

For the spring 2003 event, we can estimate the total mass transfer based on our spectral analysis, and the a simplistic assumption that the spectral energy distribution remains nearly constant in shape, with the amplitude tracing the light curve envelope (see Figure 8). This leads to a fluence of about 7×10^{43} ergs. For an efficiency of 10%, this corresponds to about 3.8×10^{-10} solar masses of material transferred. From Figure 1, its is evident that the events of this magnitude are ocurring on approximately annual time scales. The major outbursts of 1999 and 2000 execeed the 2003 event by several orders of magnitude in fluence and are more closely spaced. Thus, the disk-thermal instability models must be able to reproduce a wide variety of phenomena. We suggest that there may be more than one mechanism functioning in XTE J1550-56. For example, a small, discrete accretion event, ie. a discontinuity in the mass transfer rate which would lead in a natural way to a "fast-rise, exponential decay" (FRED) light curve. Persuing this hypothesis, we applied the Diffusive-Dissipation Propogation model (Wood et al. 2001) to the *RXTE*/ASM light curve data. This model predicts a FRED-type light curve. The resulting model fit is shown in Figure 8 where the inferred paramater of the fit, the diffusion timescale t_0, was about 71 days. The diffusion timescale is defined as $t_0 = 16R^2/3\nu(r)$ and is roughly two times the characteristic light-curve decay timescale. Assuming the disk is about half of the roche radius (e.g. de Jong, van Paradijs, & Augusteijn 1996), and using the known orbital parameters, we estimate that the accretion disk outer radius is $\sim 2 \times 10^{11}$ cm. This leads to a viscosity of $\sim 10^{16}$ cm^2/s.

Finally, we note one additional possibility. It was recently pointed out by Narayan & McClintock (2004), that XTE J1550-564 is among a subset of transient BH X-ray binaries, known to have high inclination angles ($i \gtrsim 70°$). Each of these objects have exhibited irregular outburst light curves following there initial turn-on. The two early outburst peaks, with an intermittent valley of near-zero intensity seen in Figure 1 are in that sense qualitatively similar to the outburst light curves of GRO J1655-40 and XTE J1118+48 for example. As Narayan & McClintock (2004) note, SAX J1819.3-2525 which has the highest known inclination ($i \simeq 75°$) underwent even more extreme erratic behavior, with separate outburst peaks spanning more than two orders of magnitude. This leads to the speculation that this irregular behavior may be a result of variable column densities along our line of sight, rather than to variations in the underlying outburst physics. For example, a flared outer disk of varying geometry, or with low-frequency precessional modulation could lead to such scenarios. It could perhaps then be the case that the hard, low-amplitude outbursts occur at times when the central X-ray source is highly obscured. What we are seeing in that case could be the Compton-scattered emission from a spatially extended coronal region.

5. Conclusions

We have examined the flux history and spectral characteristics of the March/April 2003 outburst of XTE J1550-564, with emphasis on its the high-energy observational coverage provided by INTEGRAL. Our major conclsions can be summarized as follows:

(i) It was an underluminous event, with a fluence more then two orders of magnitude lower than the major outbursts of that source in 1999 and 2000. There appear to be a number of such events in the long-term RXTE/ASM light curve data, which ocurr with a frequency of 300-500 days. A recurrence rate of this scale, combined with the extreme range in peak luminosity, would seem to pose significant constraints on the standard thermal-disk instability model of X-ray nova outbursts.

(ii) The source apparently remained in the low-hard spectral state throughout the duration of the outburst. There was relatively little spectral evolution, although there is evidence for a moderate softening of the spectrum towards the end of our coverage.

(iii) The spectral energy distribution is well approximated by a thermal Comptonization form. The inferred parameters, $\tau \simeq 3.5$, $kT \simeq 50$ keV, are similar to various other low-hard-state X-ray binaries. An alternative Comptonization model, which involves scattering in a divergent outflow, was fit to the data. While not conclusive, results were of comparable statistical quality to those obtained for static Comptonization models, consistent at least with the presence of outflowing plasma. Also, it is known that plasma ejection leading to radio emission is known to occur at the onset of the low-hard spectral state of variable X-ray sources.

(iv) The spring 2003 event seems to be an outlier in the $L_x - P$ diagram of Meyer-Hofmeister (2004) characterizing X-ray nova outbursts. Specifically, given its relatively long orbital period of 1.5 days, it is somewhat surprising for a low peak luminosity, $\sim$2% L_{edd}, low-hard-state outburst to occur.

(v) Given the complex outburst history of this source, as noted in item (i), combined with the approximate FRED profile of the spring 2003 outburst, we have conjectured on the possibility that multiple outburst mechanisms may be at play. In this context, we modeled the light curve profile as a discrete accretion event, undergoing diffusive propogation through the disk. This leads to a reasonable representation of the data, from which we find a $\sim$ 70-day viscous timescale, and a relatively high mean viscosity.

6. ACKNOWLEDGEMENTS

This work made use of the NASA High-Energy Astrophysics Research Archive Center (HEASARC), and the NASA *INTEGRAL* Guest Observer Facility. The Off-line Scientific Analysis (OSA) software available from the *INTEGRAL* Science Data Centre was used to perform much of the analysis in this work.

This work is based in part on observations with *INTEGRAL*, an ESA project with instruments and science data centre funded by ESA member states (especially the PI countries: Denmark, France, Germany, Italy, Switzerland, Spain), Czech Republic and Poland, and with the participation of Russia and the USA.

REFERENCES

Arefiev, V.A., Revnivtsev, M.G., Lutovinov, A.A., & Sunyaev, R.A., 2004, Astr.Let., (in press), astro-ph/0404460

Brocksopp, C., et al., 2001, MNRAS, 323, 517

Chen, W., Shrader, C.R., & Livio, M., 1997, ApJ, 491, 312

Corbel, S., Fender, R. P., Tzioumis, T., Tomsick, J. A., Orosz, J. A., Miller, J. M., Wijnands, R., & Kaaret, P. 2002, Science, 298, 196

Courvoisier, T. J.-L. et al. 2003, A&A, 411, L343

de Jong, J. A., van Paradijs, J., Augusteijn, T., A&A, 314, 484

Dubath, P., et al., 2003, IAU Circ. 8100

Goldwurm, A., et al. 2003, A&A, 411, 223

Guessoum, N., & Jean, P. 2002, A&A, 396, 157

Hannikainen, D., Campbell-Wilson, D., Hunstead, R., McIntyre, V., Lovell, J., Reynolds, J., Tzioumis, T., & Wu, K. 2001, Ap&SS Supp., 276, 45

Homan, J., et al., 2001, ApJS, 132, 377

Kaaret, P., et al., 2003, ApJ, 582, 945

Lasota, J.P., 2001, New Astr Rev., 45, 449

Lund, N., et al. 2003, A&A, 411, L223

Maccarone, T. J. 2003, A&A, 409, 697

McClintock, J. & Remillard, R. 2004, to appear in Compact Stellar X-ray Sources, eds. W. H. G. lewin & M. van der Klis (Cambridge: Cambridge Univ. press), astro-ph/0306213

Meyer, F., Liu, B.F., & Meyer-Hofmeister, E., 2000, A&A, 354, L67

Meyer-Hofmeister, E. 2004, A&A, in press, astro-ph/0406548

Miyamoto, S., Kitamoto, S., Hayashida, K., & Egoshi, W. 1995, ApJ, 442, L13

Narayan, R., & McClintock, J.E., 2004, ApJ, in press, astro-ph/0401556

Nowak, M.A., 1995, PASP, 107, 1207

Orosz, J.A., et al. 2002, ApJ, 568, 845

Remillard, R. A., Sobczak, G. J., Muno, M. P., & McClintock, J. E., 2002, ApJ, 564, 962

Rodriguez, J., Corbel, S., & Tomsick, J. A. 2003, ApJ, 595, 1032

Smith, D.A., et al. 1998, IAU Circ. 7008

Sobczak, G.J., et al., 2000, ApJ, 544, 993

Sunyaev, R.A. & Titarchuk, L.G. 1980, A&A, 86, 121

Titarchuk, L. 1994, ApJ, 434, 570

Titarchuk, L., & Shrader, C., 2004, ApJ, (in press: vol 616, astro-ph/0408261)

Tomsick, J. A., Corbel, S., Fender, R., Miller, J. M., Orosz, J. A., Tzioumis, T., Wijnands, R., & Kaaret, P. 2003, ApJ, 582, 933

Ubertini, P., et al. 2003, A&A, 411, L131

Vedrenne, G., et al. 2003, A&A, 411, L63

Winkler, C., et al. 2003, A&A, 411, L1

Wood, K. S., Titarchuk, L., Ray, P. S., Wolff, M. T., Lovellette, M. N., Bandyopadhyay, R. M. 2001, ApJ, 563, 246

Table 1. Best Fit Parameters for COMPST and COMPTT Models

ReV	Instrument	COMPST kT (keV)	τ	Norm	χ^2	dof	COMPTT kT (keV)	τ_p	Norm	χ^2	dof
55	JEM-X	39.9	3.72	0.231	352.3	206	51.5	1.43	1.86e-2	285.4	205
	ISGRI			0.236					2.07e-2		
	SPI			0.395					3.32e-9		
57	JEM-X	40.4	3.54	0.315	334.2	206	48.8	1.45	2.47e-2	279.0	205
	ISGRI			0.360					2.86e-2		
	SPI			0.584					4.51e-9		
60	JEM-X	35.5	4.06	0.255	420.4	206	42.2	1.69	1.47e-2	303.8	205
	ISGRI			0.277					1.72e-2		
	SPI			0.462					2.81e-9		

Table 2. Integrated COMPTT Best Fit Model Fluxes

Rev	Instrument	Energy Range (keV)	Photon Flux (cm^{-2} s^{-1})	Energy Flux (ergs cm^{-2} s^{-1})
55	JEM-X	3 - 30	1.49e-1	2.26e-9
	ISGRI	20-200	5.77e-2	5.37e-9
	SPI	30-300	6.97e-2	8.97e-9
57	JEM-X	3 - 30	1.85e-1	2.78e-9
	ISGRI	20-200	7.23e-2	6.64e-9
	SPI	30-300	8.49e-2	1.07e-8
60	JEM-X	3 - 30	1.71e-1	2.60e-9
	ISGRI	20-200	7.11e-2	6.56e-9
	SPI	30-300	8.68e-2	1.08e-9

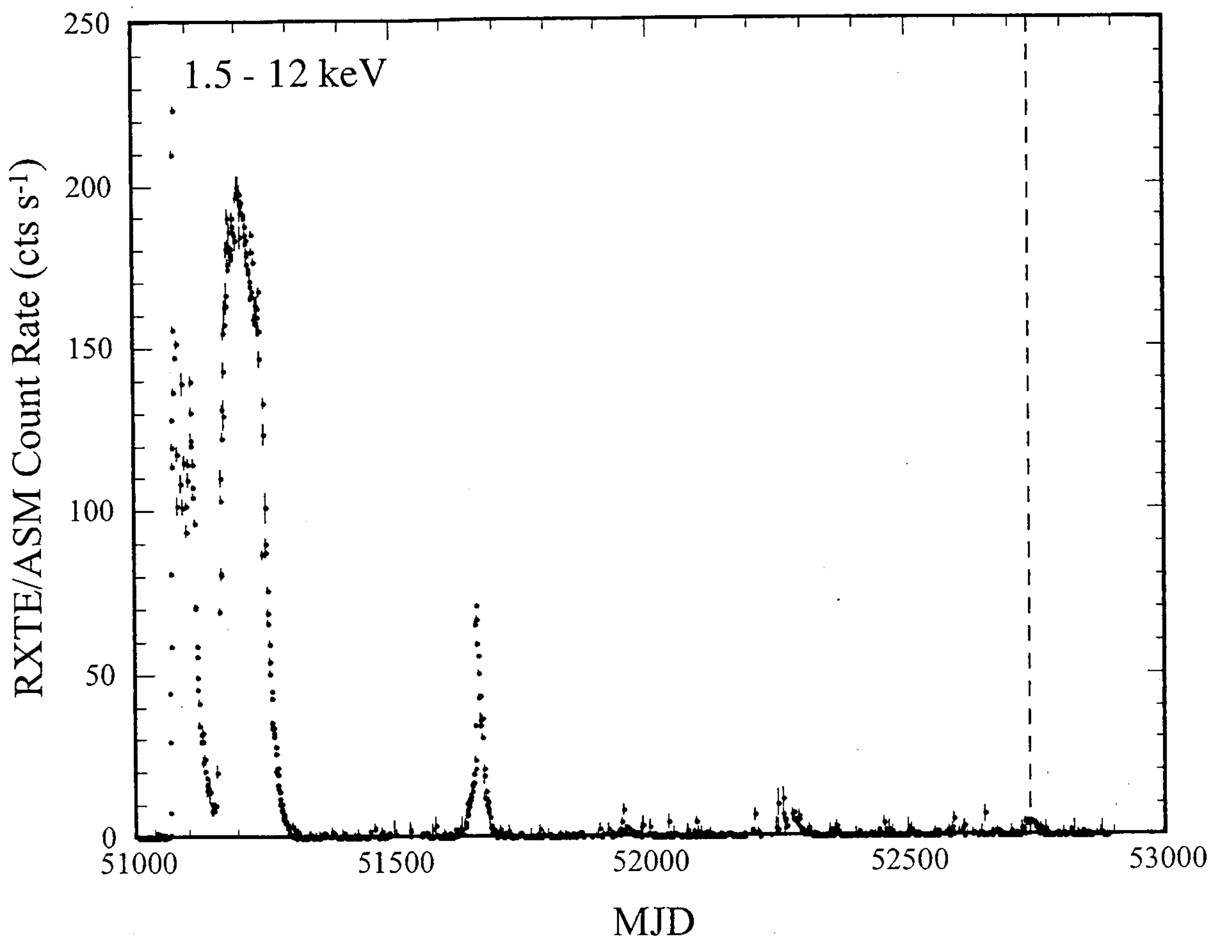

Fig. 1.— Long term RXTE/ASM (1.5 - 12 keV) light curve. Vertical dotted line overlays the March/April 2003 event. The prominient outbursts of 1999 and 2000 have amplitudes which exceed the minor flares which seem to occur with a fair degree of regularity after about MJD 5200 by more than two orders of magnitude.

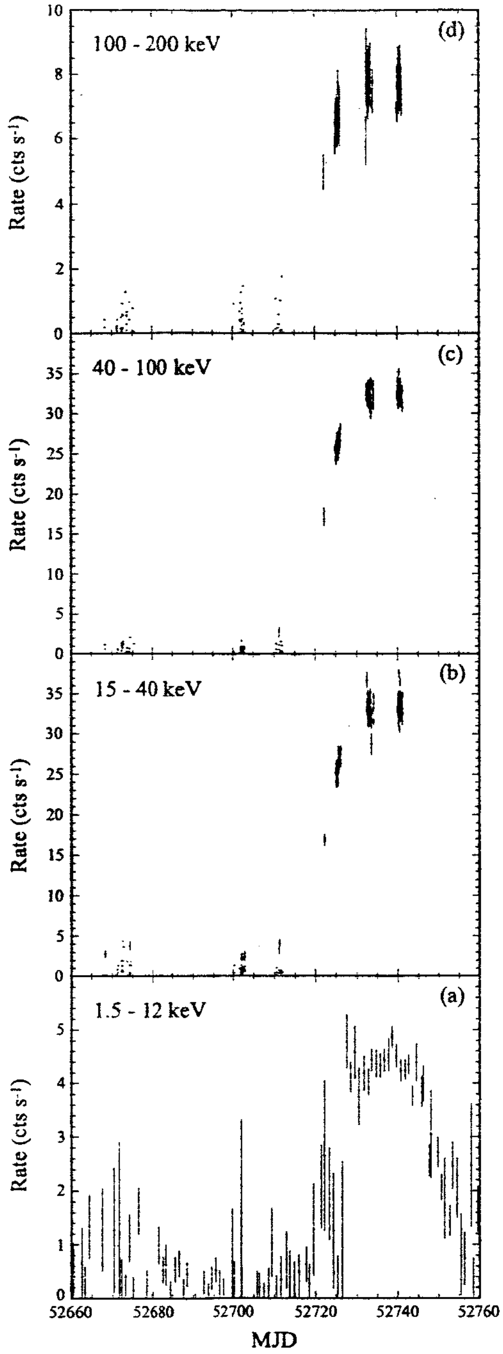

Fig. 2.— Burst light curves for the (a) RXTE/ASM 1.5-12 keV, (b) IBIS/ISGR 15-40keV, (c) IBIS/ISGRI 40-100 keV, and (d) IBIS/ISGRI 100-200 keV energy bands. The 3 INTEGRAL observations with the best statistics provide reasonable coverage of the late-rise phase and outburst peak. The lack of any extreme spectral evolution in the hard-X-ray regime is evident from comparing the three INTEGRAL energy bands.

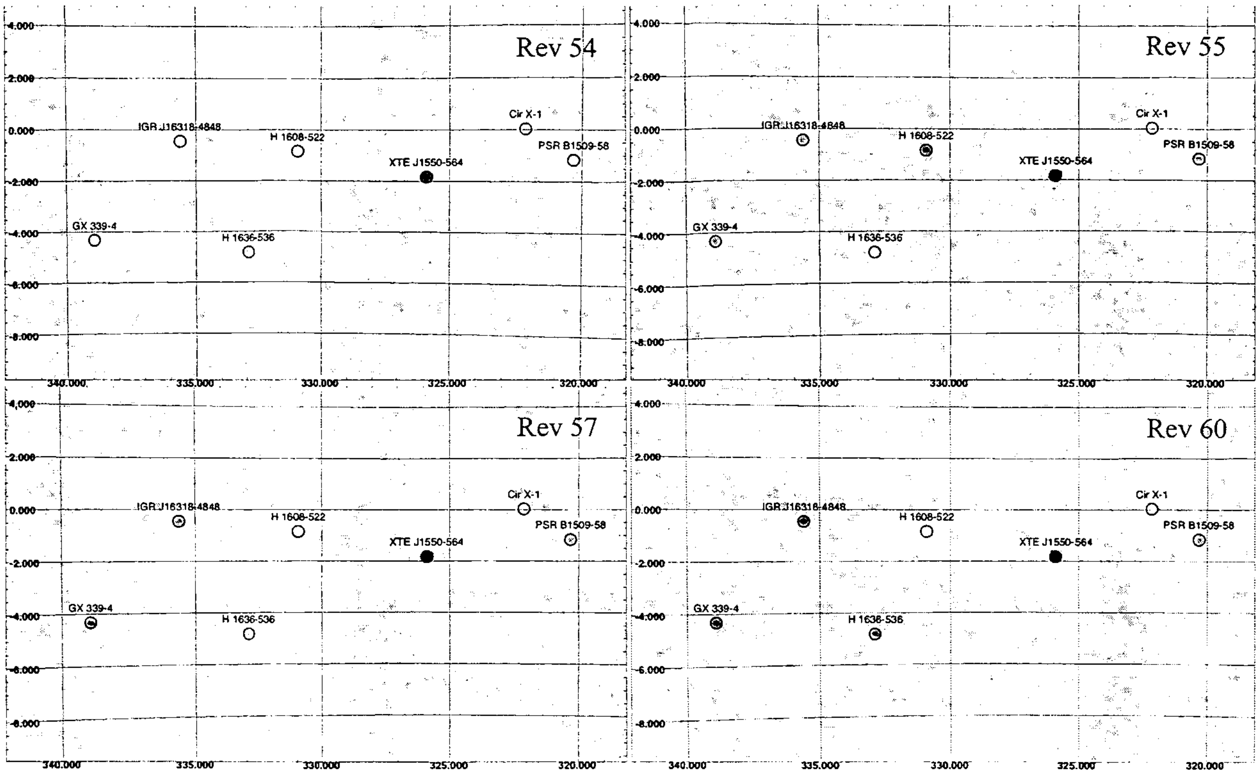

Fig. 3.— 40-100 keV IBIS/ISGRI significance images for INTEGRAL spacecraft revolutions 54, 55, 57, and 60 (approximately MJD 52724, 52727, 52733, and 52741). Note how XTE J1550-564 brightens significantly from revolution 54 to revolution 55. Also note that H 1608-522, H 1636-536, IGR J16318-484, and GX 339-4 also show significant variability during this time period.

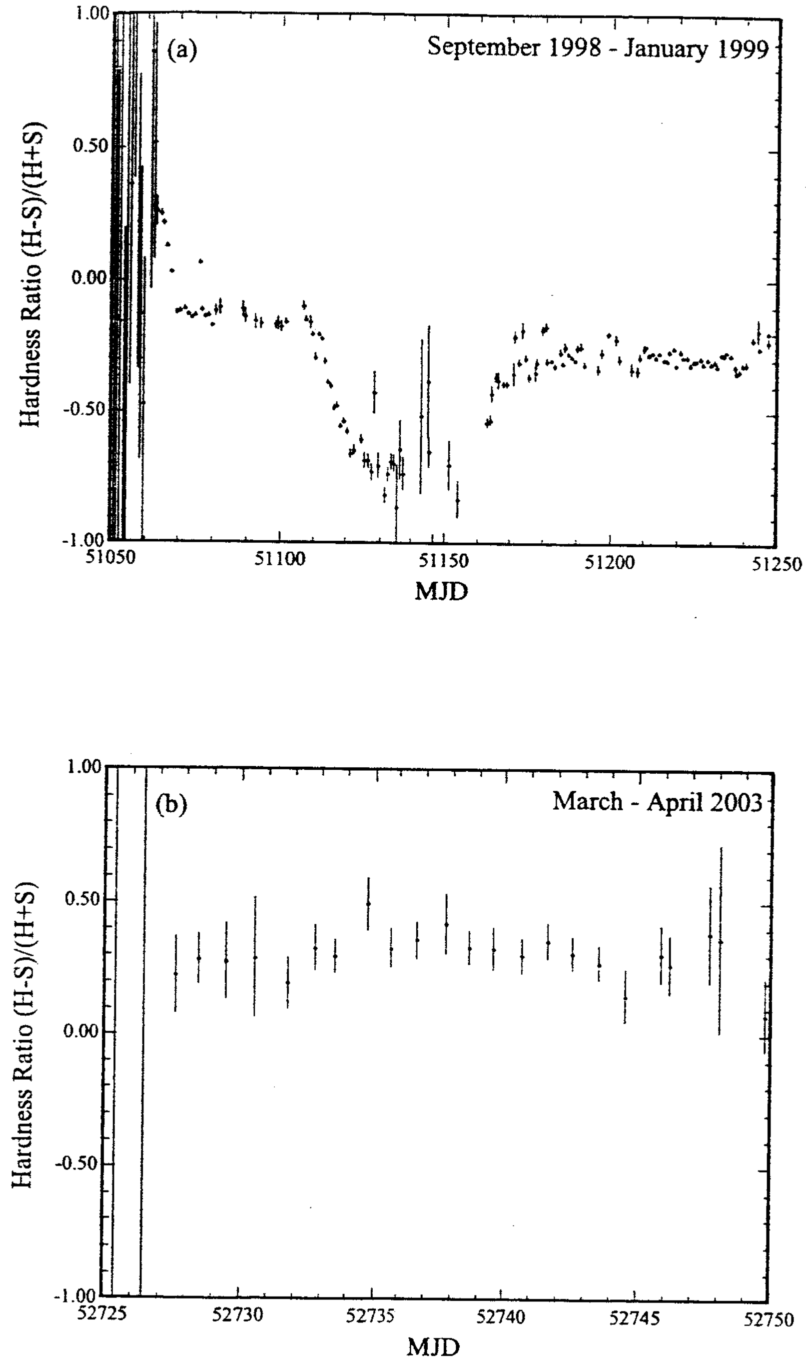

Fig. 4.— A comparison of the 5-12 keV (H) to 1.5-3 keV (S) hardness ratios for the major January 1999 outburst and the March-April 2003 outburst. Here we have defined the hardness ratio as (H-S)/(H+S). Note that the ratios are roughly constant in both cases but at very different values.

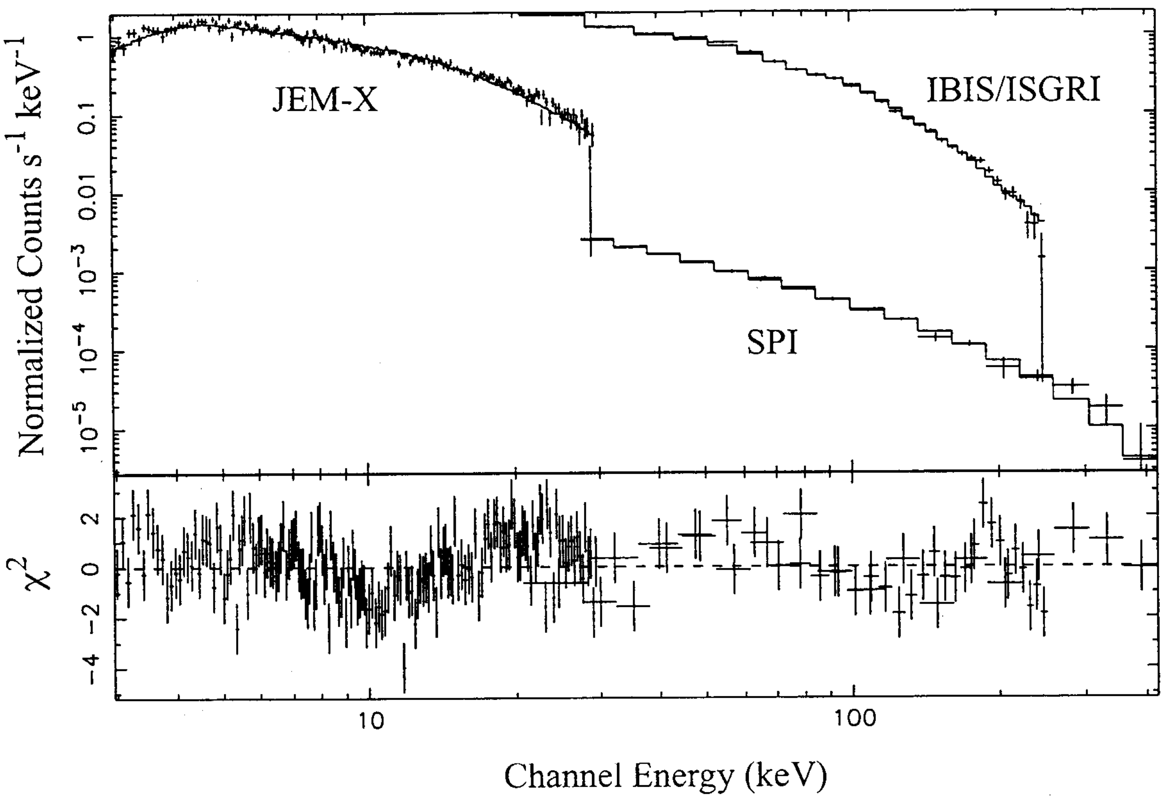

Fig. 5.— The JEM-X, IBIS/ISGRI, and SPI data for XTE J1550-564 for revolution 57 as well as the best-fit COMPTT model. Also shown are the deviations of the model from the data in units of χ^2.

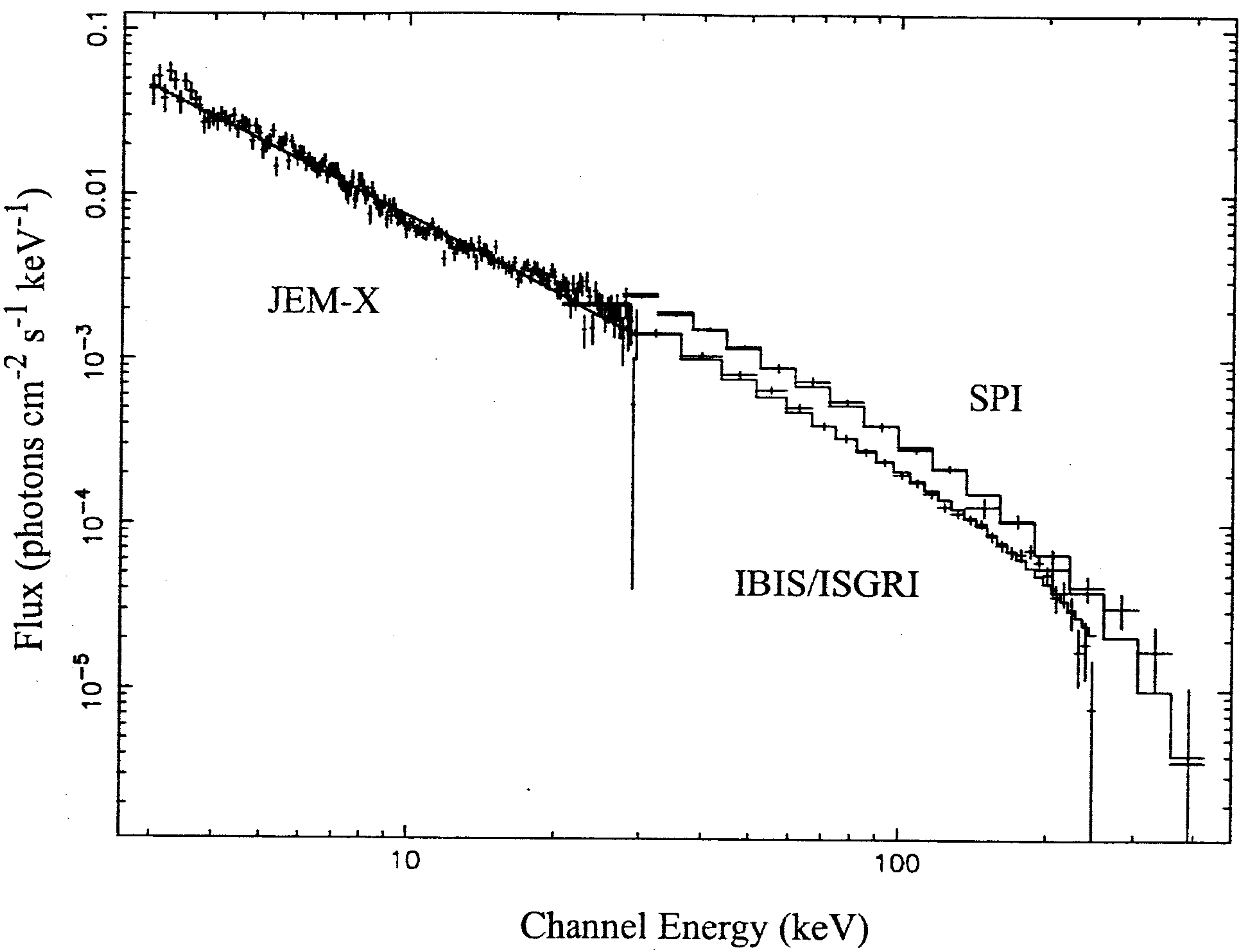

Fig. 6.— The JEM-X, IBIS/ISGRI, and SPI unfolded data for XTE J1550-564 for revolution 57 as well as the best-fit COMPTT model. The instrumental cross-calbration discrepencies are evident.

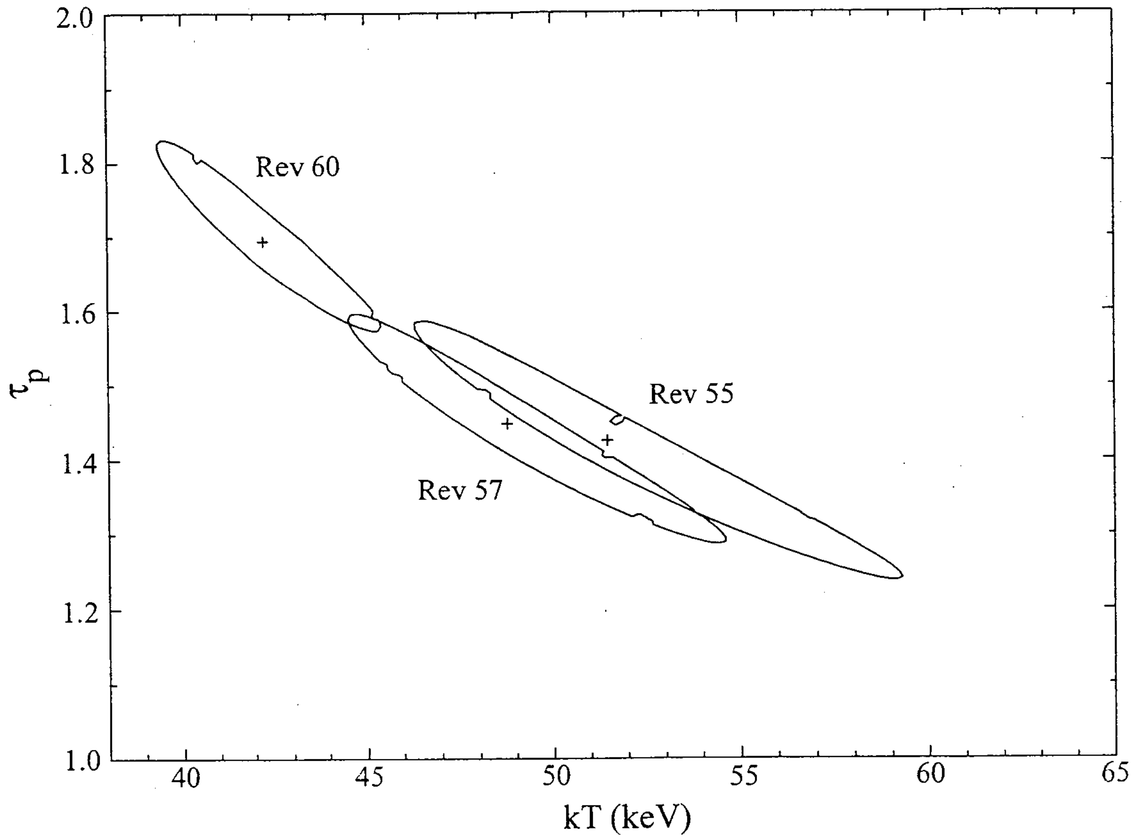

Fig. 7.— Here we show the evolution of 90% confidence error contours for the parameters kT and τ_p of the COMPTT model.

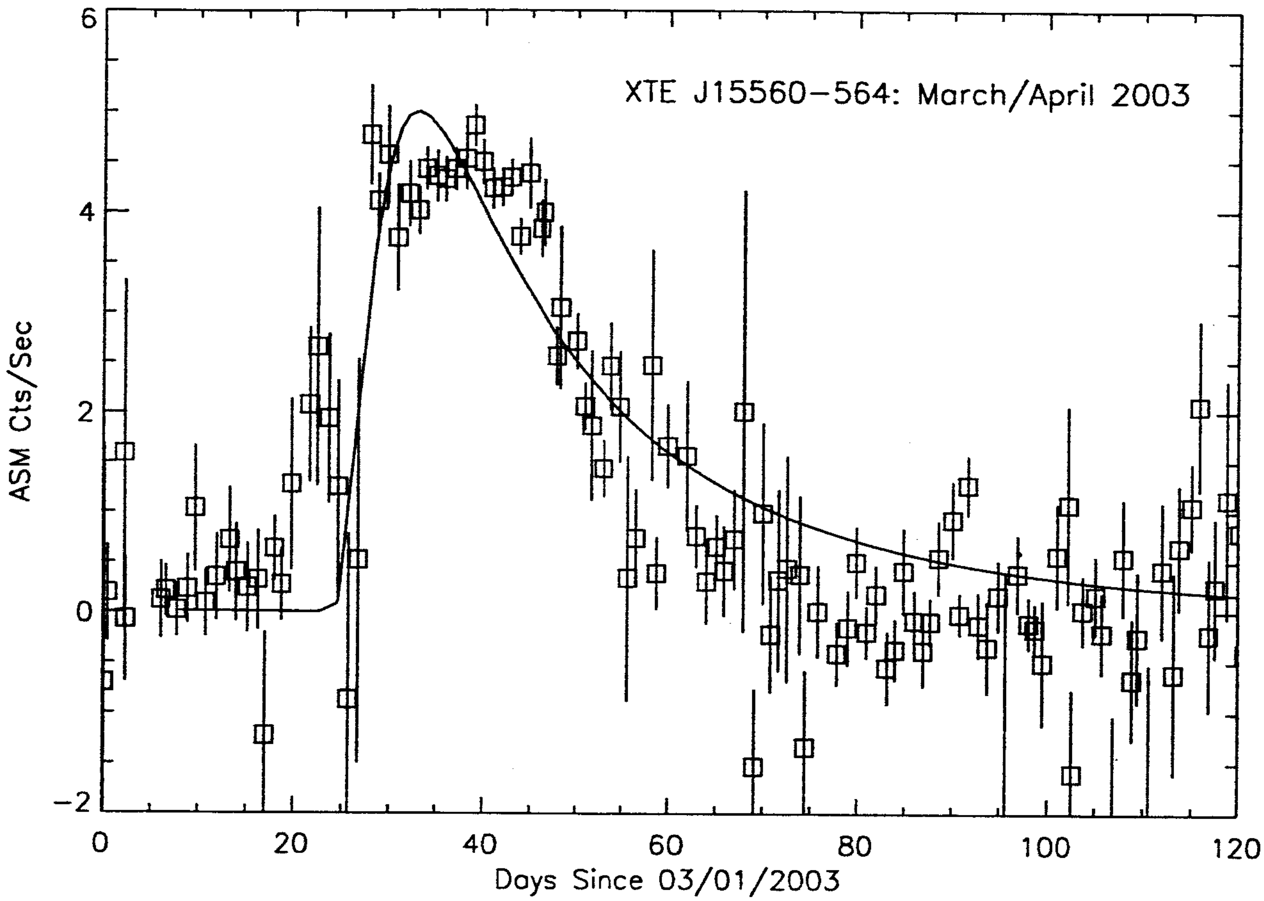

Fig. 8.— The ASM summed-band (i.e. 3-12 keV) is plotted as detector count rate, versus days with a zero point at March 1, 2003. For perspective, the ASM registers about 75 cts/s for the Crab. The FRED-like profile, possibly even with a secondary maximum event (see Chen, Shrader & Livio 1997) about 20 days after the initial rise make it quite distinct from the major outbursts of 1999 and 2000 in terms of both shape and amplitude. The smooth curve overlaying the data results to least-chisquare fit to the data based on the diffusive-disk propogation model of Wood et al (2001). That model is predicated on a discrete accretion-rate increase